BIOMECHANICS OF SUSPENDED-CIRCLES ON POMMEL HORSE: WHAT IF KNEES ARE SUSPENDED?

Toshiyuki Fujihara[1] and Pierre Gervais[2]

Faculty of Physical Education, Osaka University of Health and Sport Sciences, Osaka, Japan[1]
Faculty of Physical Education and Recreation, University of Alberta, Edmonton, Alberta, Canada[2]

Training aids form a fundamental component of gymnastic training. Previous research has shown how a suspended aid changes biomechanics of circles on pommel horse. Building on these findings, the aim of the current study was to examine the influence of a modified use of the aid through the suspension of the gymnast at different positions. Discriminative biomechanical variables, which were identified in the previous research, were analysed to compare circles performed by a single gymnast between two conditions: with the aid around his knees and around his ankles. The results showed that changing the location of suspension had influences on both kinematics and kinetics of circles, implying the possibility of various use of a suspended aid.

KEY WORDS: gymnastics, body weight support, training aid, progression.

INTRODUCTION: A suspended aid is a training aid used by a gymnast to practise skills on pommel horse. It is most commonly used in the introductory stage of learning circles, the most basic skill in pommel horse exercises (Figure 1). Because an aid suspends a gymnast's legs from above, it is relatively easy for a beginner to experience the overall motion of circles. Coaching literature also recommends the use of a suspended aid for a more advanced gymnast to refine his technique (e.g. Karácsony & Čuk, 1998).

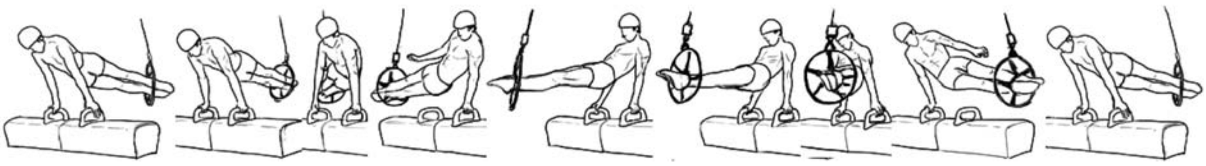

Figure 1: Circles performed with the suspended aid (ankle-suspended).

Previous studies reported the influences of using a suspended aid on several variables during circles. First, average reaction forces from a pommel horse were reduced by approximately 20-30% (Fujihara & Gervais, 2011a). Second, the amplitude of circle motions, measured by trajectory and body-angle data as suggested by Baudry et al. (2009), was generally increased with the aid (Fujihara & Gervais, 2012a). Third, the reaction force from the aid altered hip joint moment profiles during circles (Fujihara & Gervais, 2011b). Moreover, the amount of support from a suspended aid depended on the gymnasts' levels of expertise (Fujihara & Gervais, 2012b). According to these previous studies, using a suspended aid influences kinematics and kinetics of circles while reducing the wrist load. Some changes due to the use of the aid can be an intention of training, but other changes may not. For instance, the force attenuation on the wrists can be a useful option for a variety of training purposes, but the alteration of net hip joint moments could delay or hinder the transition from circles with the aid to without. Building on previous research (Fujihara & Gervais, 2011a, b, 2012a, b), the next logical step was to examine how the mechanical alterations due to the use of the aid changes if a gymnast is suspended in a different way.

Figure 2: Knee-suspended circles.

The objective of this research was to develop and test a novel use of the aid and extend the possibility of this training method. Although a suspended aid is traditionally attached to feet or ankles, the aid used for the previous studies could suspend a gymnast from his knees without any modification (Figure 2). By attaching the aid about the knees, the moment arm of the external force (aid reaction force) about the hip joint would be significantly reduced compared to the traditional usage of the aid (Figure 3), and therefore the alteration or hip joint moment profiles would be decreased. Testing such a modified use of the aid will enhance our understanding of this training method.

METHODS: Employing the procedures previously outlined (Fujihara & Gervais, 2011a, b, 2012a, b) can supplement information about the methodology because this research shared many procedures with them.

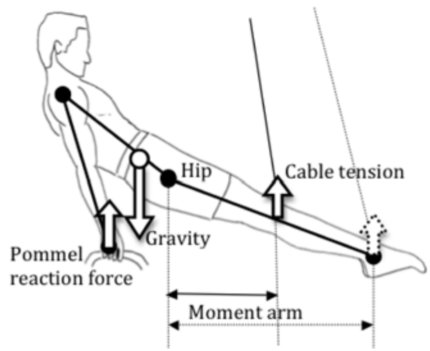

Figure 3: A shorter moment arm for the cable tension when the aid is attached to the knees instead of ankles.

Experimental set-up: A no-leg pommel horse was cut into two halves, and each half was fixed to a force plate (AMTI, OR6-6-4000). A suspended aid was constructed using a rotator-twisting belt (Figure 1&2). The cable tension was measured with a single-axis load transducer (LCCB-500, Omega Engineering Inc.) embedded between the cable and the twisting belt. Three-dimensional coordinates of the retro-reflective makers attached to the anatomical landmarks were captured using 13 Qualisys ProReflex cameras operating at 100 Hz. The force data were recorded with the motion capture system via an analogue board (USB-1616FS, Measurement Computing) at 1000 Hz.

Data collection and analysis: After a warm-up, a skilled male gymnast performed three sets of 10 circles in each of three conditions: with the aid around the ankles, with the aid around the knees, and without the aid. University Ethical approval was gained for all experimental protocols, and the gymnast provided written informed consent. For each set of 10 circles, 7 circles (3rd – 9th) were used so that the mean data for each condition were computed from the data of 21 circles. The 3-D coordinates data were smoothed using a fourth-order Butterworth digital filter at the optimal cut-off frequencies (3.3 Hz – 8.2 Hz) determined by automatic algorithm of Yokoi and McNitt-Gray (1990). Hip joint centres were estimated using Halvorsen's algorithm (2003), and all other joint centres were estimated as the centres of two markers attached on the surface of each joint. The force data were filtered at 100 Hz and scaled to the gymnast's body weight. The following variables were selected from the previous study: aid reaction force, pommel reaction force, total duration, horizontal diameters of shoulder and ankle trajectories (shoulder diameter, ankle diameter), body flexion angle, shoulder extension angle during the rear support, and hip joint moments (Fujihara & Gervais, 2012b). The computational description for these variables can be found in the previous studies (Fujihara & Gervais, 2011a, b, 2012a, b). For aid and pommel reaction forces, only the vertical component was considered. The average resultant force from the two pommels represented the pommel reaction force. The amplitude variables (shoulder diameter, ankle diameter, body flexion angle, shoulder extension), identified by Baudry et al. (2009), and total duration were selected as discriminative kinematic variables. Based on the hip joint moment profiles during circles with the aid as analysed in Fujihara and Gervais (2011b), the average flexion-extension moment was computed for the front and rear support phases using inverse dynamics, and the average lateral-flexion moment was computed for the entry and exit phases (Figure 1 for the phase definitions). The single-subject analysis could partially be supported by the fact that the previous work showed reasonable levels of between-gymnast reliabilities for these variables (Fujihara & Gervais, 2011a, 2012a).

RESULTS AND DISCUSSION: Although the external validity was limited in the sense of a single participant, the results had some implications about the influences of changing the location of suspension. The magnitude of the force attenuation by the use of the aid was very similar between the ankle- and knee-suspended conditions, but the kinematic and kinetic alterations were more moderate in the knee-suspended conditions (Figure 4).

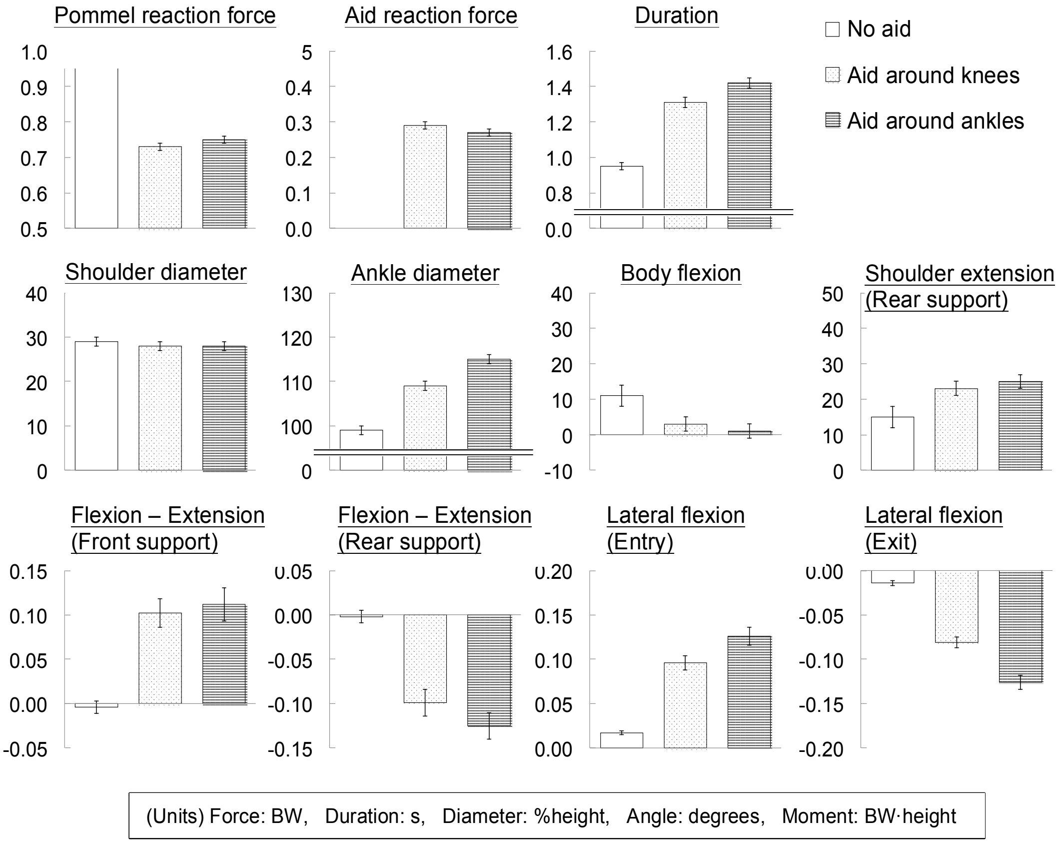

Figure 4: The comparison of discriminative variables among circles with no aid, circles with the aid around the ankles, and circles with the aid around the knees. Each bar shows an average of 21 circles with ±1 standard deviation.

In terms of the discriminative kinematic variables the knee-suspended circles were generally more similar to no-aid circles than the ankle suspended circles (Figure 4). The ankle diameter was increased in both ankle- and knee-suspended trials, but the knee-suspended circles showed smaller ankle diameter than the ankle-suspended circles (109% height vs 115% height). Similarly, the use of the aid reduced the body flexion and increased the shoulder extension in both knee- and ankle-suspended conditions, but the difference from the no-aid trials was slightly smaller for the knee-suspended condition. The shoulder diameter was very similar among three conditions. In other words, the aid assisted the gymnast in improving the amplitude of circles regardless of the point of suspension, but the knee-suspended circles were slightly closer to the no-aid circles than the ankle-suspended circles were. There are two possible explanations for this. During circles with no aid, the knees generally have less vertical motions than the ankles. For this gymnast, the range of vertical motion was approximately 0.24 m for the ankle centre and 0.12 m for the knee centre during circles with no aid. Because the cable that suspended the aid was non-elastic, the vertical motion of the suspended part of the legs was strongly constrained. The influence of this constraint was more significant for the ankle-suspended condition because of its greater potential for vertical motion. Second explanation is that the height of the aid kept the ankles

at very high elevation during the ankle-suspended trials. The aid was set as low as possible without contacting the pommel horse. However, the ankles were positioned in the centre of the aid, so it was approximately 0.2 m higher than the pommel horse. In the knee-suspended conditions, the ankles could go lower, resulting in a more similar motion to no-aid circles.
The duration for a knee-suspended circle was slightly shorter than that for an ankle-suspended circle. This difference could be primarily attributed to the decrease in the moment of inertia due to the aid. Fujihara & Gervais (2012a) explained that having the aid at the distal part of the body increased the moment of inertia of the body. In the knee-suspended condition, this additional mass was closer to the mass centre of the body, resulting in the smaller moment of inertia for the same mass increment. Although the speed of circles was still based on the individual's comfort in both the knee- and ankle-suspended trials, the influence of the greater moment of inertia was decreased in the knee-suspended circles.
As hypothesised, suspending the legs from the knee region reduced the alteration of the net hip joint moment. This was most likely achieved by the decrease in the length of the moment arm for the aid reaction force relative to the hip joints. In the front support, however, there was no practically significant difference in the net hip joint moment between the knee- and ankle-suspended trials. In this phase, the mean aid reaction force was actually greater for the knee-suspended circles than for the ankle-suspended circles (0.27 BW vs 0.21 BW), whereas the differences in the other phases were smaller than 0.02 BW. It seemed that the difference in the length of the moment arm was compensated with the difference in the magnitude of the aid reaction force, causing a similar amount of the external moment on the leg segment. These results confirmed that the point of suspension largely, but not solely, influences the changes in the net hip joint moment profiles during the circles with a suspended aid.

CONCLUSIONS: The results implied the potentials for suspending a body from a point that is more proximal to the centre of rotation. However, as soon as legs are suspended at anywhere more proximal than the knee region, the gymnast would start to get tangled with the cable that suspends the aid. To avoid this problem, another structure is needed, and therefore the practical simplicity of this type of aid will be lost. This dilemma has been tackled but not yet solved. For now, it would be most practical to understand the mechanical consequences of using a traditional and simple aid, to use it according to its aim in training in a variety of situations, and to integrate the aid training with other training that could compensate for the downside of the training with the aid. The findings of this research add practical as well as further scientific contributions to understanding key skill progression and developing effective training for pommel horse.

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